12.4 Channel Optical Waveguides and Directional Couplers in GaAs—Imbedded and Ridged, S. Somekh, E. Garmire, and A. Yariv, *California Institute of Technology, Pasadena, Calif. 91109,* and H. L. Garvin and R. G. Hunsperger, *Hughes Research Laboratories, Malibu, Calif. 90265.*

(15 min)

The development of useful integrated-optics circuits requires channel waveguides of small dimensions fabricated with close tolerances. We shall discuss techniques for forming smooth channel guides in semiconductors such as GaAs, with dimensions of the order of a few microns and show their application to directional couplers.

We have fabricated imbedded single and dual channel guides by proton implantation through a gold mask. A gold layer, 2 μm thick, was ion machined through a photoresist mask to form a proton-resistant barrier. The implanted guides have dimensions of 3×3 μm and are single mode in both confinement directions, an important requirement for many optical circuit elements. We measured a single channel loss of 6 cm^{-1} for the first-order mode; this loss is determined by the particular implanting conditions. We have found that ion implantation provides an excellent means of making smooth imbedded optical circuits. The statistical nature of implantation and the annealing help to smooth out any mask imperfections so that the presence of channel walls does not substantially increase the losses. Furthermore the protons directly copy complex circuits from a gold mask into imbedded single-mode guides. We shall discuss details of fabrication techniques and more extensive loss studies.

Our dual channel guides had a width of 3 μm and a separation of 3.5 μm. These channels form the conventional optical directional coupler; complete transfer of light energy from the input to the output channel was observed in dual channels 2 mm long. This coupling length was expected from the channel dimensions and measurements of coupling strength[1] and is convenient for most optical circuit applications. The demonstration of a dual channel coupler in electrooptic material suggests a modulator or switch formed by controlling the coupling with an applied electric field. Recent work in this area, both experimental and theoretical, will be discussed.

We formed ridged guides on epitaxial films of GaAs (high resistivity grown on low resistivity substrates) by ion micromachining through a photoresist mask. The surface of the photoresist is replicated in the epitaxial layer by the milling action of the ion beam.[2] Single channels a few microns in size have been fabricated, guiding observed, and losses measured. The walls were made sharp and smooth by using holographically prepared masks and by tilting the sample at various angles with respect to the bombarding ion beam during machining. Electron micrographs of our channels show edge deviations less than a few hundred angstroms. This also suggests that instead of cleaving, a smooth edge can be ion machined to make good terminations to imbedded or ridged channel guides. Our ion machining seems to be sufficiently smooth to fabricate the mirrors for semiconductor lasers and may even allow curved mirrors in order to increase the cavity Q.

In ridged channels, the modes are well confined in the plane of the guide because of the large dielectric discontinuity at the ridge-air interface. Thus, two closely spaced ridged guides will have negligible coupling. To increase the coupling between channels, only a partial removal of the epilayer between them was performed. In these guides, we observe coupling from the input channel to adjacent channels. The coupling strength depends on the thickness of the epilayer bridge between channels. The coupling between two ridged channels can also be increased by filling the region between them with another material with a slightly different refractive index, for example by sputtering. Work in this area is in progress.

[1] Somekh, Garmire, Yariv, Garvin, Hunsperger, *Appl. Phys. Lett.*, Jan. 1, 1973.
[2] Garvin, Garmire, Somekh, Stoll, Yariv, *Appl. Opt.*, Mar. 1973.

12.5 Second-Harmonic Generation in a Guided Wave Structure Consisting of Quartz Coated With Glass Film, Y. Suematsu, Y. Sasaki, and K. Shibata, *Tokyo Institute of Technology, Tokyo, Japan.*

(15 min)

An optical parametric interaction due to the guided waves along a dielectric waveguide offers certain advantages over the conventional methods with the new possibilities for phase matching, with the tuning properties, with the energy concentration, and with the possibility of integration of the devices. This paper contains an experimental observation of the phase-matched SHG using a guide consisting of quartz coated with a glass film for the visible spectrum. The pump was a YAG laser. The experimental results were in agreement with the theoretical results.

The samples were prepared by RF sputtering of the Corning 7059 glass on the Y-cut quartz. The c axis of the quartz was chosen to be along the direction of propagation. The samples were 30 mm long and 20 mm wide. The thickness of RF-sputtered glass film had a small gradient along the transverse direction and it was adjusted by a back sputtering process to give stronger interactions. The refractive index of the glass film was 1.568 at the wavelength $\lambda = 0.63$ μm and the relative refractive index difference between the film and the quartz was $\Delta = 1.6$ percent. The theoretically estimated phase-matching thickness of the glass film is 2.51 μm.[1]

The peak pumping power on the guide was approximately 300 W. The modes of the pump were TM_{01} and TE_{01}. The maximum output power was 0.03 W at the thickness $2b$ of about 2.6 μm and at an interaction length of 6 mm. The mode of the SH was TE_{03}, and the scattering loss

[1] Y. Suematsu, K. Akiyama, H. Yokoi, and Y. Sasaki, *Trans. Inst. Elec. Commun. Eng. Japan*, vol. 55-C, p. 106, Feb. 1972.

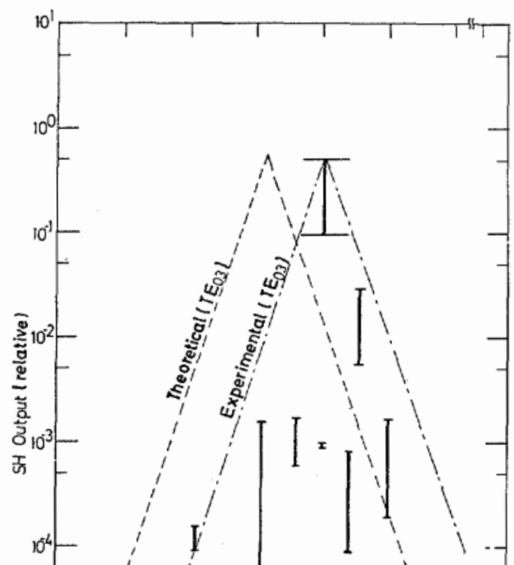

Fig. 1. Output power of SH versus film thickness $2b$.